

The use of fuzzy control methods for evaluation of complex systems on the example of maritime fleet equipment

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Abstract. At present, the interest in application of synchronous machines in the various systems of the electric drive and energy sources is still growing. Synchronous motors and their modifications enable to develop low-noise, reliable and economically efficient electric drive systems. They provide high maneuverability when using a propeller power plant of the submersible vehicles and the World fleet vessels. Synchronous generators are the major energy sources in the electric power systems of the variety autonomous plants: on vessels, offshore and coastal oil rigs, etc.

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1. The development of the maritime industry in drilling

Most calculation methods have not changed significantly, but have been tested a number of experimental tests and structured in the form of formulas and tables of acceptable values. All of this documentation can be found on the website of the Russian Registry of Shipping. Changing the shape and size of the hull or its parts caused by external forces or other influences (e.g., heating, cooling). Distinguish between General and local deformation. When the overall body is deformed as the hollow beam of variable cross section and may have a common longitudinal bending, transverse shear total and total torsion. General buckling is characterized by changes of curvature of the neutral axis of the hull in the vertical and horizontal planes of the ship, the total transverse shear - rotation normal to the cross section of the hull relative to the neutral axis, and the total torsion - angle of twist relative cross sections of the hull [1-3]. Automation of technological processes made possible to achieve the enhanced quality and increased profits in the various spheres of the industry where it was implemented.

Market of floating production systems (FPS) continues to be one of the largest. Thanks to improve of technologies the significant growth in the use of popular FPS with underwater pumping was noted at the market of offshore projects since the mid of 90-ies. Since then, production using FPS has increased significantly and amounted to 25 % as of the end of 2014. In 2010, the production with their aid has reached the peak of 8.4 MM bbls/d, and, according to forecasts, by 2020 it will be about 9.4 MM bbl/d. Douglas-West-wood notes serious losses of FPS in 2015. The largest investments by volumes are now directed to the creation of floating plants for production of liquefied natural gas (FLNG), which may be the most common solution on the Australian and Asian markets. Today, seven such projects are at the stage of construction and designing. However, so far the world has not commissioned any production based on FLNG. The first such project “Kanovit” should be brought to operation at Petronas on Malaysia offshore in 2016.

2. Analysis of the status of marine equipment. Electrical power

The fundamental estimation of stocks volumes of Arctic hydrocarbon does not exist: The United Nations gives a figure of 100 billion tons of oil and 50 trillion cubic meters of gas.

Geological Services of USA and Denmark estimate oil reserves in the Arctic as 83 billion tones or 13 % of the world's undiscovered deposits. A significant portion of oil reserves lies near Alaska, and the main gasbearing fields are located at the coast of the Russian Federation.

It should be noted that the process of offshore drilling is the most complex in the development of hydrocarbon deposits (at depths of more than a kilometer). The drilling technologies of high reliability and maintainability are necessary, which are now lacking entirely in the industry and it leads to increased need in large investments in the development of offshore production technologies and attracting of new technologies.

The study of Russian industry market conditions shows that to ensure manufacture of equipment for the development of offshore fields is not possible in its entirety (up to 90 % of the equipment is supplied by imports and the imposed sanctions have also substantial negative impact).

There is no doubt in the fact that the reliable data obtaining for decision-making by the operator of marine intelligent control terrosystems (MICT) in conditions of uncertainty and risk of the environment requires sufficient completeness of the analysis methods and models of inaccuracies and uncertainties of data in MICT. In this connection it is necessary to analyze the models and methods of inaccuracies and uncertainty of MITC data. Traditionally two means of providing incomplete data are used: the theory of probability and the theory of errors. However, these theories have a number of limitations and in the probabilistic model the limiting case of a complete fuzzy knowledge is taken into account badly, because the set of mutually independent events is always assumed as given, the equal probabilities (in the finite case) are attributed to which by virtue of the maximum entropy principle [3-5].

At the same time a great deal of ship's automation systems applies the line currents and voltages to form the reference signal. Thus, for example, an automatic voltage regulator (AVR) of ship's synchronous generators (SG) performs regulation by an average value of voltages and currents of the circuit. However, with the distorted form of the variable signals (that is caused by the presence of a wide range of highest harmonics) their average value increases and an automatic voltage regulator (AVR), correcting the error, decreases the exciting current of the synchronous generator that results in loss of voltage in the ship's electric power systems (SEPS). Consequently, decrease in relative value and increase in highest harmonics take place and so electromagnetic moment of non-synchronous motors decreases, the level of interferences influencing the systems of ship's automatic controls becomes higher, and losses in power supply lines enlarge. Practically such an error is corrected by adjustment of the voltage corrector (VC). However, as harmonic composition periodically varies depending on the regime of operation and the composition of load of the electric power station, the setting of the voltage corrector should be changed constantly. This problem should be solved by measuring the level of the basic harmonics of the current and voltages of the ship's circuit.

On the other side it is known, filter-compensating devices (FCD) are the most efficient means to increase the quality of electric energy in the ship's power supply systems at the moment. Their efficiency in higher harmonic suppression and compensation of their volt-ampere reactive may be provided only with the high accuracy of the calculation of parameters in the target harmonics of the line currents and voltages. Thus, the required functional set of the systems taken as an example determining their efficiency in particular and their operational performance in general, is set for identification of external parameters of the control system. The major function of the block is extraction of harmonic components required for their analysis, calculation of their parameters from the distorted signal and application of results of that analysis in control of means of the increasing values for quality of the electric energy in the ship's electric power systems. With this, such parameters as levels of target harmonics of currents and voltages, values of summary harmonic distortions, values of distortion capacity, volt-ampere reactive, etc. are regulated. The setting of the problem. If sources of energy for ship's electric power station may be represented as a generator of the sinusoidal signal:

$$x(t) = a_1(t)\sin(\omega_1(t)t + \varphi_1(t)),$$

where $a_1(t)$ – amplitude, $\omega_1(t)$ – rate of phase change and $\varphi_1(t)$ – phase – non-stationary parameters of the generator;

The present paper proposes to use certain function approximating the target harmonics of the distorted signal. Identification of the target non-stationary harmonics of the distorted signal is made by adjustment of the parameters of the relevant function-prototype (FP). In its general form the input signal $y(t)$ of the identification system being a signal proportional to the circuit current or voltage in the ship's electric power system may be described by Fourier's series:

$$y(t) = \sum_{k=1}^N a_k(t)\sin(k\omega_k(t)t + \varphi_k(t)) = x(t) + \xi(t), \quad (1)$$

where $a_k(t)$ is amplitude, $\omega_k(t)$ is a rate of phase change and $\varphi_k(t)$ is a phase angle of k -harmonics, N is a number of harmonics (in general $N = \infty$), $\xi(t) = \sum_{k=2}^N a_k(t)\sin(k\omega_k(t)t + \varphi_k(t))$ is a set of non-approximated (i.e. non-recoverable by the device being designed) harmonics.

Let's introduce the vector for parameters $\phi(t) = [a(t), \omega(t), \varphi(t)]^T$, which belongs to the space of parameters $\Phi(t) = \{ [a, \omega, \varphi]^T \}$. The approximation error is exhibited by the expression:

$$\varepsilon = y - \hat{x}, \quad (2)$$

where $\hat{x}(t) = \hat{a}_1(t)\sin(\hat{\omega}_1(t)t + \hat{\varphi}_1(t))$ is a recovered harmonic component. Moreover, it is evident that the more components $\xi(t)$ of the function will be recovered by the relevant generators of the approximating functions the less error Eq. (2) will be.

3. The solution of the task outlined

The core of the proposed principle of the approximation of every harmonics of the measured signal is in the formation of the periodical function basing on the function-prototype $R_k(\omega_k(t), \varphi_k(t), t)$, where k is a number of the approximated harmonics (or simply $R_k(k, t)$); so changing its parameters we will strive to approach the minimum of the error between the input signal and periodical function. Proceeding from the physical sense of the processes under the review, as it was stated above, it is reasonable as FP to use the function $R_k(t) = \sin(\omega_k(t)t + \varphi_k(t))$. Thus every harmonics will be approximated by the weight function (Dirac response) $\hat{x}_k(t) = \hat{a}_k(t)R(k, t)$. Thus the frequency $\omega(t)$ and phase function $\varphi(t)$ of the target function are variable, so let's go to the notion of the complete phase $\psi(t) = \omega(t)t + \varphi(t)$, taking into account all the variations of the function phase [5-8]. The system will be expressed as:

$$\frac{d\hat{a}(t)}{dt} = -\mu_A \varepsilon(t)\sin\hat{\psi}(t), \quad \frac{d\hat{\omega}(t)}{dt} = -\mu_\omega \varepsilon(t)\hat{a}(t)t\cos\hat{\psi}(t). \quad (3)$$

The energetic function would be expressed in the form of the following expression:

$$E(t) = \frac{1}{2}[y(t) - \hat{a}(t)\sin\hat{\psi}(t)]^2, \text{ i.e. for the error of the approximation we will have } \varepsilon(t) = y(t) - \hat{a}(t)\sin\hat{\psi}(t) = y(t) - \hat{x}(t).$$

It should be noted that the change in the phase of the input signal may be compensated by the similar change in the initial phase of the approximating function (that will exactly correspond to the behavior of the signal being approximated), short-time change in the frequency of the same function or by the combination of these processes.

Let's pass on the integral of the function Eq. (3) and the final interval $[t_i - T/2, t_i + T/2]$ of

T duration, where one more interval of FP is determined. As one can see, FP used by us is 2π -periodical (i.e. $T = 2\pi/\omega$) and odd-symmetrical in respect of the middle of the interval where it was determined and integrated. Let's assume that the amplitude of the approximated harmonics for the time of the FP period does not change (or changes slowly). So for the basic harmonics we will have:

$$\hat{\omega}_1(t) = -\mu_{\omega 1} \int_{t_i - \frac{T}{2}}^{t_i + \frac{T}{2}} \varepsilon(t) \hat{a}_1 t \cos \hat{\psi}(t) dt. \quad (4)$$

Considering and taking into account that according to the experimental research [1-4] odd harmonics are predominant in the ship's circuit, express Eq. (4) in the following:

$$\begin{aligned} \hat{\omega}_1(t) = & -\mu_{\omega 1} \int_{t_i - \frac{T}{2}}^{t_i + \frac{T}{2}} [a_1(t) \sin \psi_1(t) + a_3(t) \sin \psi_3(t) \\ & + a_5(t) \sin \psi_5(t) + \dots] \hat{a}_1(t) t \cos \hat{\psi}_1(t) dt. \end{aligned} \quad (5)$$

In the connection with that only odd harmonics will take place in the input signal, so under the mark of the integral vice versa only even harmonics with frequencies $2\omega_1, 4\omega_1, 6\omega_1$ etc. will remain, and the integral of their sum in the interval T will be equal to 0 due to the even non-symmetry of the sine components.

Let us consider the set events associated with the base of inaccurate and uncertain knowledge understood as subsets of the universal set Ω called certain event. The empty set \emptyset is identified with the impossible event. It is assumed that to each event $A \subset \Omega$ real number $g(A)$ can be put in correspondence, which is given by the subject – “keeper” of the knowledge base (or obtained by the procedure of processing of the information stored in the information system memory). Value $g(A)$ evaluates degree of certainty available to the subject in relation to the event A considering current level of awareness. By definition, the value $g(A)$ grows with certainty increasing. Furthermore, if A is the certain event, it is assumed that $g(A) = 1$, and if A is an impossible event, then it is believed that $g(A) = 0$.

Hence, the measure is determined by the function: $g: P(\Omega) \rightarrow [0,1]$, where $P(\Omega)$ – cardinality of a set Ω . In order to consider the function as a fuzzy measure, it should have the following properties of fuzzy measures, it should have the following properties of fuzzy measures: $g(\emptyset) = 0$; $g(\Omega) = 1$ – limitedness; if $A_1 \subseteq A_2$, then $g(A_1) \leq g(A_2)$ – monoteness; if $A_1 \subseteq A_2 \subseteq \dots$ or $A_1 \supseteq A_2 \supseteq \dots$, then $\lim_{i \rightarrow \infty} g(A_i) = g \lim_{i \rightarrow \infty} (A_i)$ – continuity. The requirement limitedness is obvious. The requirement monoteness does not allow a subset of the other subset Ω have more than including subset. According to the requirement continuity, the measures limit of infinite monotonous sequence of subsets Ω should coincide with the limit measure of this sequence. To the discrete systems, in which Ω is always a finite set, the continuity requirement, of course, does not apply. These set functions g were proposed by Sugeno for estimating the uncertainty called fuzzy measures. Dubois and Prades used the name “uncertainty measure”. Inequalities follow directly from the monotony axioms and characterize the sum $A \cup B$ or intersection $A \cap B$ of events: $\forall A, B \subseteq \Omega, g(A \cup B) \geq \max(g(A), g(B)), g(A \cap B) \leq \min(g(A), g(B))$. The limiting case of uncertainty measures is functions of set L such that $\forall A, B, L(A \cup B) = \max(L(A), L(B))$. They are called measures of possibility by Zadeh. The measures of possibility satisfy the relation: $\max(L(A), L(\bar{A})) = 1$.

4. Practical implementation. Conclusion

The formulate models of scalar multifactorial estimation, methods of regularization of

ill-posed problems, the theory of interval analysis to account for the uncertainties of the original data, machinery of probability theory, fuzzy sets, equally probable intervals to account for uncertainties, expert evaluation method to determine the order relation on the initial set of alternatives, methods of comparator identification and genetic algorithms to solve the problems of structural-parametric identification of evaluation model were used in the work for solving the problems of utility theory.

Currently, there is no universal, invariant kind of uncertainty and measurement metric is “uncertainty”, so when making decisions specialized task-oriented metrics are applied. This circumstance determined the separation of decision-making problems in conditions of uncertainty into three main classes.

Regardless the synthesis methods of the multifactorial assessment model include the uncertainty due to the subjectivism of initial information sources. Currently this uncertainty in most cases is not taken into account in the intellectual support systems of decision-making for drilling platforms operators.

A general approach to solving problems of multi-criteria optimization taking into account the uncertainties of the marine environment consists in decomposition of the original problem into a sequence of two conditionally independent tasks: formation of scalar deterministic multi-factorial assessment; decision-making under conditions of uncertainty of the environment.

The simplicity of the proposed algorithm allows to implement multivariable approximator with minimum requirements to the computational hardware of the device. The simplest and the most effective algorithm with computational function or a FP tabular model may be implemented in the FPGA. FPGA architecture, its flexibility and possibility to implement parallel computational processes makes them the most promising platform for the practical implementation of the reviewed tracking system. The model provides the report for the parameters of one harmonic of the input signal, produced by means of block Xilinx Resource Estimator.

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